DOCUMENT RESUME

ED 122 739 IR 003 322

AUTHOR Heaphill, John M., Jr.; And Others
TITLE Program Evaluation and Review Technique (PERT): A Planning and Control Tool for Occupational Field Studies.
INSTITUTION California State Univ., Los Angeles.
SPONS AGENCY Office of Naval Research, Arlington, Va.
PUB DATE Sep 75
NOTE 55p.; Not available in hard copy due to marginal reproducibility of original document

EDRS PRICE MF-$0.83 Plus Postage. HC Not Available from EDRS.
DESCRIPTORS *Critical Path Method; Decision Making; Management Education; *Management Information Systems; Management Systems; *Manpower Utilization; Military Training; Occupational Information; Operations Research; Planning; Program Evaluation; *Sequential Approach; *Task Analysis
IDENTIFIERS Marine Corps; Occupational Field Study; PERT; *Program Evaluation and Review Technique

ABSTRACT

Program Evaluation and Review Technique (PERT) is used in the U.S. Marine Corps task analysis program for occupational field studies. Scheduling sequential tasks, estimating time requirements, determining staffing needs, and locating checkpoints for control all can be accomplished using PERT. Examples of operational aspects of PERT, PERT schedules, time estimations, and management of occupational field studies are provided. This presentation will be of most use to new personnel for planning and control of occupational field studies, and to persons interested in task analysis as conducted by the Marine Corps. (CH)

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PROGRAM EVALUATION AND REVIEW TECHNIQUE (PERT): A PLANNING AND CONTROL TOOL FOR OCCUPATIONAL FIELD STUDIES

John M. Hemphill, Jr., C. Harold Stone
and Dale Yoder

Technical Report No. 3

EVALUATION OF THE MARINE CORPS TASK ANALYSIS PROGRAM

A Research Project Supported By

Commandant of the Marine Corps (Code RD)

And Monitored By

Office of Naval Research
Personnel and Training Research Programs
Psychological Sciences Division
Contract No. N00014-74-A-0436-0001
NR 151-370

IR003322

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September, 1975

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CHAPTER 1

INTRODUCTION

An Occupational Field (OF) study in the Marine Corps Task Analysis Program is a project that involves completing specific study steps in a logical sequence. Several identifiable activities or tasks are performed over a period of time to complete each study step. Before an OF study begins, past experience in the Office of Manpower Utilization (OMU) can be used to define virtually all of the sequence of activities necessary to complete the study and to identify the major events (or points at which study steps are completed) that must occur in the process. Therefore, the technical process of the OF study can be decribed with some precision before it starts.

The problem then is to generate a plan for implementing the project and a technique for controlling it throughout. At this point, PERT can be especially useful in developing a detailed implementation plan -- including scheduling work, estimating time requirements, determining staffing needs, and pinpointing check points for reports on and control of the OF Task Analysis (TA) study.

PERT is a management tool that makes possible more accurate, more objective, and more rapid planning, reporting, and control in a complex project. Applied research by the ONR-MC Task Analysis Project Staff has suggested that a full description of PERT and its applications to OF study projects would be of

operational value to OMU.

PERT was originally conceived as a project monitoring device and as a way of allocating scarce resources, including time. The objectives in using PERT in OMU include:

- Fostering increased orderliness and consistency in planning and evaluating all areas of OF studies.
- Providing an automatic mechanism for the identification of potential delays or trouble spots.
- Structuring a method to give operational flexibility to projects.
- Facilitating the handling and interpretation of reports on project progress and problems to permit timely warning and preventive or corrective action.

The use of PERT can provide tangible evidence of effective project management.

This report is designed to serve two purposes. First, it can be used as training material for new personnel to introduce them to techniques of planning and control in OF studies. Second, it can provide a timely reference for individuals directly involved in designing, directing, planning, controlling and participating in OF studies.*

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*Some of the material in Chapters 2, 3, and 4 were adapted from M. W. Mueller and W. A. Nielsen, PERT Training Manual, Lockheed California Company, January 1962. (By permission)

CHAPTER II

OPERATIONAL ASPECTS OF PERT USE IN OMU

OVERVIEW

PERT is a management tool that helps the organization reach its objectives in a systematic, clearly defined way. In OMU, PERT could be used to define and manage each project with greater precision than previously used methods. It could be used for analyzing a plan rapidly so that many alternative plans can be considered, and proposed plan changes can be evaluated quickly and objectively. PERT can also be used to warn of schedule difficulties sufficiently in advance of occurence to permit orderly correction. To summarize, PERT can be used by OMU as follows:

PHASES	PERT USES
I. Planning	Preparing project schedule.
II. Execution	Controlling adherence to schedule. Evaluating proposed changes.

THE PLANNING PHASE

One way to proceed in the Planning Phase would be as follows:

STEPS	ACTIONS
1	Identify individuals responsible for conducting a new OF study, who are directed to develop the PERT schedule.
2	Direct these individuals to develop the list of events or milestones describing the progress of the project and determine activities that must be performed to progress from one event to the next.
3	Assemble information from Step 2 into a flow chart network which defines topical relationships between these events and activities.
4	Provide preliminary time estimates for all activities in the network.
5	Analyze time estimates to determine overall expected length of the project, areas in which time can be shortened, potential sources of delay, etc.
6	Determine and schedule manpower requirements in each stage of the project period.
7	Review PERT schedule with OMU top management, and revise as appropriate; the schedule becomes the plan for Execution Phase.

Step 1 is a responsibility of top management. Assuming a "Study Unit (or OF-TA Team) approach" -- with officers selected to head the new OF study, supplemented by NCOs as required -- these officers are then given the responsibility for completing Steps 2-6.

In application, Steps 2 and 3 would not be as time-consuming

as they may appear. On the basis of experience in several OF studies that have been completed, a generalized project flow chart has been developed (see Appendix A). Steps 2 and 3 would entail adapting this generalized flow chart to the new OF study and refining, or revising, events or activities as appropriate.

To complete time estimates in Step 4, the OF Study Team could draw from its own experience in OF studies and poll other knowledgeable OMU members. Allowances for any unique aspects of the new OF study might have to be made. For example, an OF with relatively few Marines might require much less time to complete activities related to inventory administration than would an OF with a larger Marine population. Highly technical OFs might require more time in activities related to the Study Phase than would low-technology OFs. (More discussion on estimating time requirements is provided in the next chapter.)

Steps 5 and 6 require the OF-TA Study Team to review carefully its time-event network regarding:

1. Acceptability and feasibility of overall project length.
2. Potential trouble spots (delays) during the project period.
3. Manpower allocations and manpower skills needed at specific points during the project period.

Top management reviews and evaluates the PERT schedule in Step 7, and revisions may be made. The result of completing this step is a tailor-made, specific plan for execution of the OF study.

THE EXECUTION PHASE

Once a project is under way, PERT becomes a control which raises a warning flag whenever schedule slippage or other problems are imminent. It also becomes an evaluation device for assessing alternate courses of action or departures from the original schedule.

During execution of an OF study, the actual time required to complete activities is substituted for estimates. The effects upon subsequent activities and events can be quickly determined if more or less time has been required to complete work than was planned. Top management can anticipate resource needs by each OF Study Unit because the work flow process is planned and monitored. For example, coordinated PERT scheduling among OF studies might reduce the problem of "peak demand" for computer time or clerical assistance. If delays occur, more manpower resources within OMU might be required to achieve project time goals. On the other hand, if less time is needed than had been estimated, resources would be available for transfer to other OF studies requiring additional manpower.

In actuality, during the Execution Phase, revised time estimates represent amendments to the origianl plan. This information as well as identification of activities that have been completed indicates:

- whether the likelihood of completing the entire project on schedule has changed;
- which activities require management corrective action to preserve the time schedule;
- which activities are potentially in trouble from a scheduling point of view;

- which activities are currently under control.

PERT LIMITATIONS

The primary functions of PERT are to warn of scheduling delays, and to aid management in anticipating future events. PERT identifies slippage areas and warns when and where the slippages will occur. However, PERT does not generally identify the cause of trouble, nor does it tell how to remedy it.

When suggestions have been made to correct a schedule slippage, PERT can be used to evaluate the correction and to predict whether or not further corrective action will be necessary.

PERT is a management tool that aids decisions-makers. It is not a substitute for management decisions and does not justify dispensing with any of management's functions. PERT merely helps managers to review and analyze complex problems, and to make decisions more promptly and accurately.

CHAPTER III

HOW TO DEVELOP THE PERT SCHEDULE

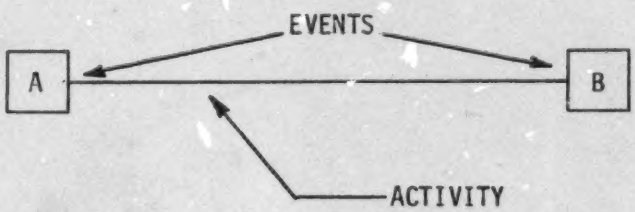
GENERAL DESCRIPTION

The PERT description of a project consists of three elements:

1. Events or Milestones
2. Activities
3. Networks

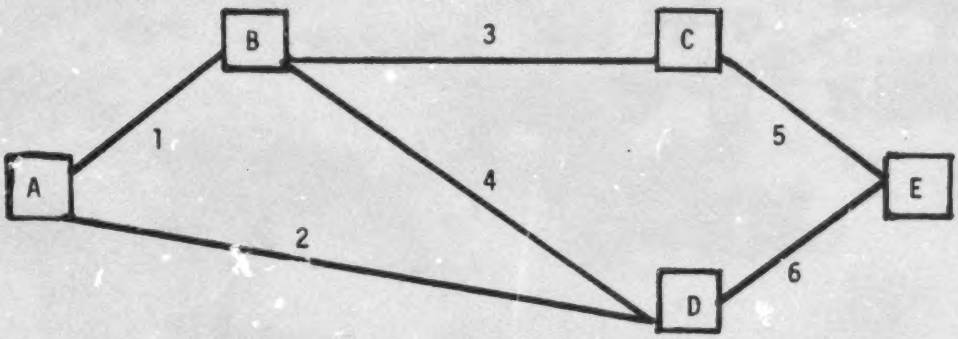
Events are well-defined occurrences, such as completion of one study step, and are graphically represented by squares, circles, or ovals.

Activities are the operations that permit progressing from one event to the next. They are represented by lines.



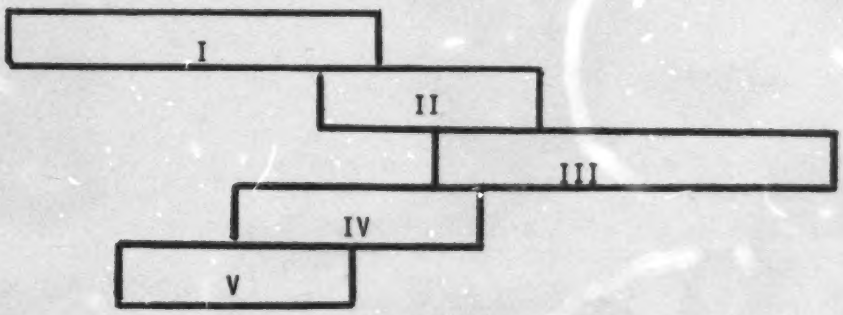
To proceed from Event A to Event B, some work must be done or some time consumed. This is represented by the connecting line. The length of the line has no significance.

A network is a flow chart that shows the relationship between the events and the activities that make up a project.

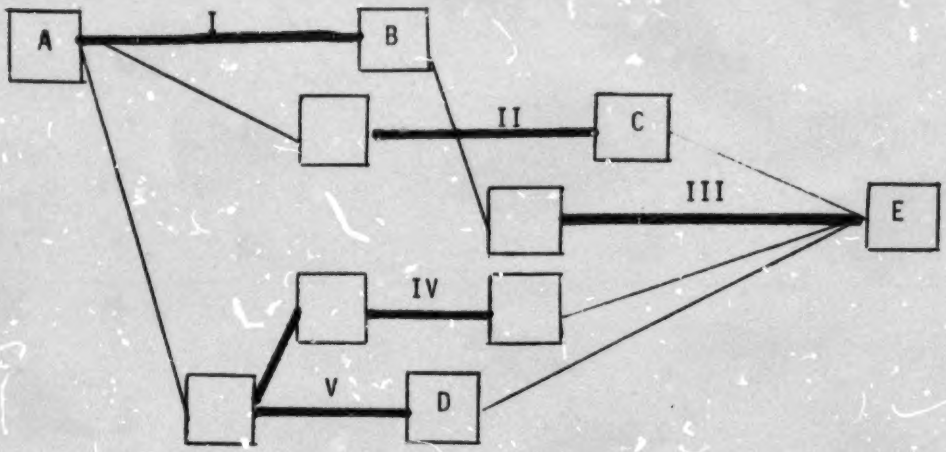


Thus, a network is an easily visualized representation of sequences and interrelationships among the events and activities of a project. This PERT representation of information is somewhat more explicit than the conventional bar chart. This is because the network indicates the interrelationship among events and not merely the amount of overlap among them. The extra information on the PERT network makes it easier to discuss and visualize a project. to adjust schedules, to avoid problems, and to analyse slippages.

A bar chart can be converted into a PERT network. For example, consider the following chart:



In PERT form, this chart could appear as follows:



Note that each bar becomes a line with an event at its start and finish. The Roman numerals identify the correspondences between the bar chart and the PERT diagram. In the PERT diagram, however, additional activity lines (the light, unnumbered lines) have been added to show the interrelationships among activities and additional squares (unlabeled) that may justify inclusion by their contribution to the total achievement. It is now clear, for example, that Activity III cannot start until Activity I is completed, and that the start and finish of Activity III is independent of Activity II. This added information makes the PERT network more precise and meaningful than the bar chart.

All bar charts consisting of five bars do not, of course, translate into the specific network shown above. The particular network can be drawn only if the interrelationships among bars are known. Thus, the PERT network requires more precise input knowledge; but because it does so, it represents the project more precisely.

SPECIFIC DEFINITIONS

The general description of events and activities and how they make up a network provides basic information on how PERT describes a project. To provide a better understanding of the concept, however, more detailed definitions and more explicit explanations of the PERT network are necessary.

Events

An event is a definite point in time which coincides with the beginning and/or end of a specific task or activity. It must be defined precisely.

Examples:

1. Study step started
2. Monitor and sponsor meeting held
3. Task inventory construction started
4. Initial routing of report started

An event is represented on a network by a square, circle, or oval. A typical event looks like this:

Trouble develops when an event is not defined with sufficient precision to assure that all parties understand and agree on when it will occur. To avoid such confusion, an event should be described in precise language so that:

1. It means the same thing to all persons concerned.
2. It indicates what specifically must have occurred to consider the event reached.

3. It associates the event with something sufficiently tangible to permit independent verification of its occurrence.

Experience has shown that most trouble occurs when:

1. An event is defined incorrectly as a continuing process and not as a definite point in time.
2. The words used to describe an event do not mean the same thing to everyone concerned.

In general, events should be expressed in the past tense. This makes it less likely that continuing processes will be described.

Improper	Proper
Firm-up	Task inventory completed
Finalize (finish)	First draft report completed
Send	Report mailed for review

If the event can be tied to the start or completion of something tangible, it is easier to agree on when it has occurred.

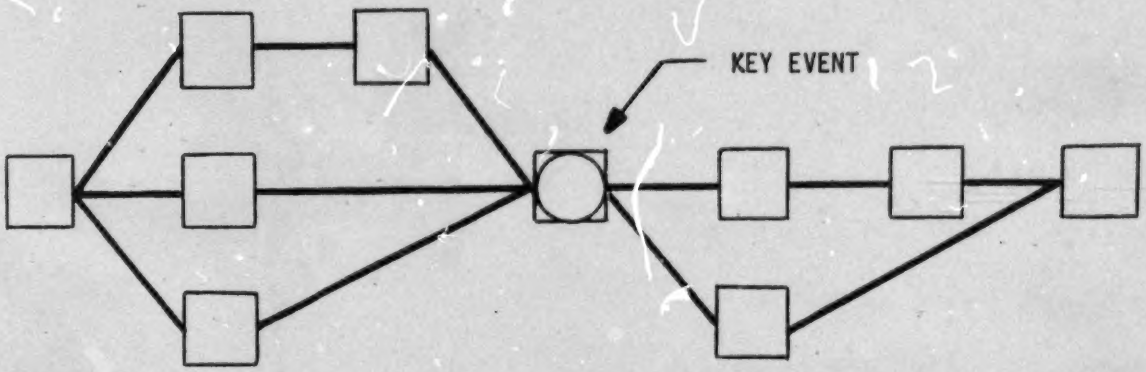
Many intangible events such as "Decisions reached" can be better defined as occurring only when some physical action has taken place. Thus, "Statement of decisions issued" means the decision was reached, written down on paper, and issued. This can be checked by anyone.

If such procedures cannot be followed, it is wise to consider an event as reached only when the person completing the activity leading to it, and the person responsible for the activity leading from it, sign a simple statement to that effect.

An event identified on the network by both a square and a circle, , or in some other equally distinguishing way, is a key event or major milestone. Such an event is of particular interest because:

1. It could represent culmination of a group of important activities.
2. It may have to be reached before other important activities can be started.
3. It is a focal point within the network.
4. It is tied to some important management control other than PERT, such as the budget or a top management mandate.

In the following network, the key event is a natural focal point because all activities funnel through it.



The first and last events in a network are always of major importance, and it is not necessary to represent them with a circle and square.

An event with a date beneath it is a scheduled event set by a management requirement.

Example:

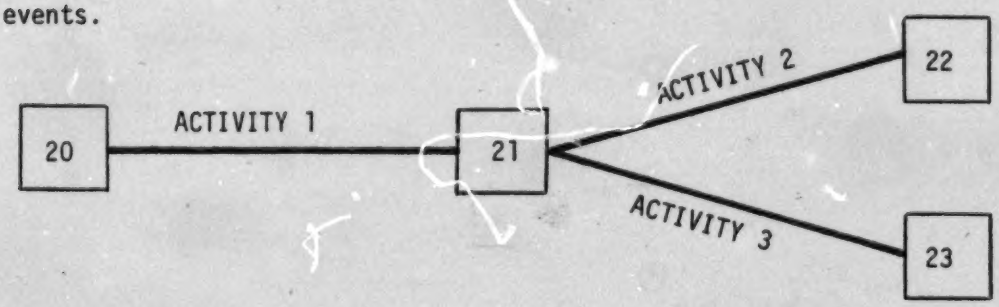
1 JAN '76

Frequently such events are also key events.

Activities

An activity is an operation that takes time, manpower, or money; it takes place between one event and the next immediate event.

In the PERT system, an activity is represented by a line connecting two events.



An activity has one and only one predecessor event and one and only one successor event. In the illustration:

Activity 1 has only one predecessor (20) and only one successor (21);

Activity 2 has only one predecessor (21) and only one successor (22)

Activity 3 has only one predecessor (21) and only one successor (23)

An activity being an action or operation, it is best described by an action verb.

Improper	Proper
Task statements reviewed	Review task statements for clarity
Clearances requested	Obtain area or security clearance
Other OF studies reviewed	Review other OF studies

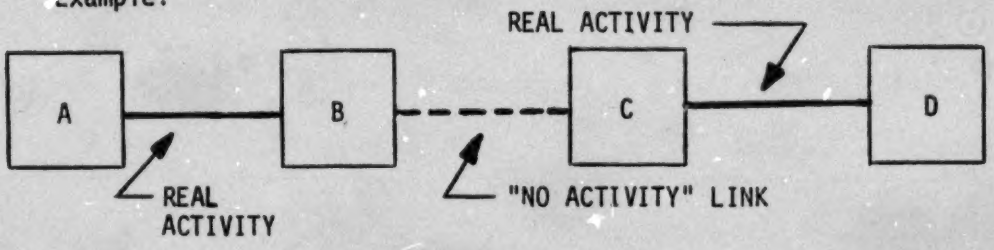
An important consideration in the description of an activity is that it have a definite beginning and end. Those that continue indefinitely are not usable in most cases. Continuing activities should be broken down into parts, so that each has a definite beginning and end.

Improper	Proper
Hold study team meetings	Hold first study team meeting
Prepare progress reports	Prepare June, 1976 progress report
Request personnel	Request personnel for inventory construction

No-Work Activities - A "no-work" or "zero-time" activity is used to connect events which logically must follow each other, but require no work or time.

Such a "no-work" activity is represented on the network with a dashed line, or a time value of "0" placed next to a solid line.

Example:



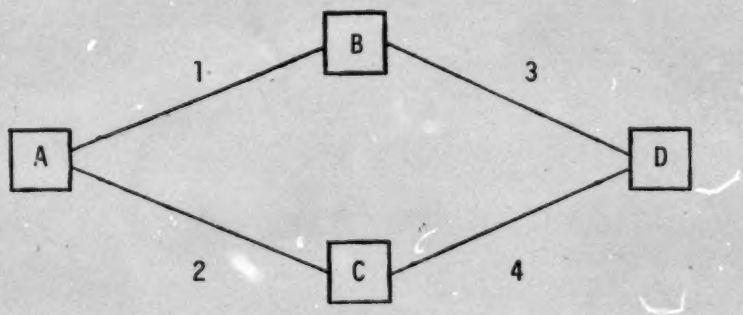
If Event B in the above example were "Study Phase Completed" and Event C were "Task Inventory Construction Started", then it is appropriate to connect them with a no activity dashed line to indicate:

1. Event B must precede Event C
2. No work occurs and no time necessarily elapses between Events B and C.

Networks

A network is a flow chart that defines the interrelationships among the events and activities that make up a project.

Example:



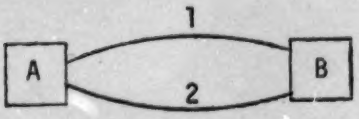
This network starts with Event A and ends with Event D. (PERT diagrams "flow" from left to right.) This network shows that:

1. Activities 1 and 2 can start only after Event A is reached.
2. Event B is reached only after Activity 1 is completed; Event C is reached only after Activity 2 is completed.
3. Activity 3 can start only after Event B is reached; Activity 4 can start only after Event C is reached.
4. Event D is reached only after both Activities 3 and 4 are completed.

Rules. There are several important rules that must be followed in making a network. Failure to follow these rules causes ambiguity in the meaning of the network.

1. Only one activity may connect two adjacent events.

Improper



Proper

2. Every event except the first must have a predecessor, and every event except the last must have a successor event.

If necessary, no-activity lines should be added to avoid having dangling events.

This rule assumes that every event is on an unbroken path of activities leading from the beginning to the end of the network. This is required for slack analysis described in the next chapter.

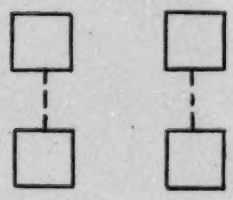
3. Activities may not loop back on previous events.

The logic involved in developing the network should be demonstrated in events progressing from left to right over time.

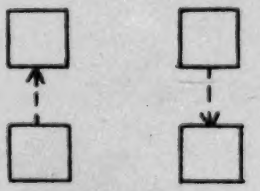
4. If two or more events occur simultaneously, no-activity lines (vertical in this case) must have a direction arrow to indicate which is the successor event.

NB

Improper



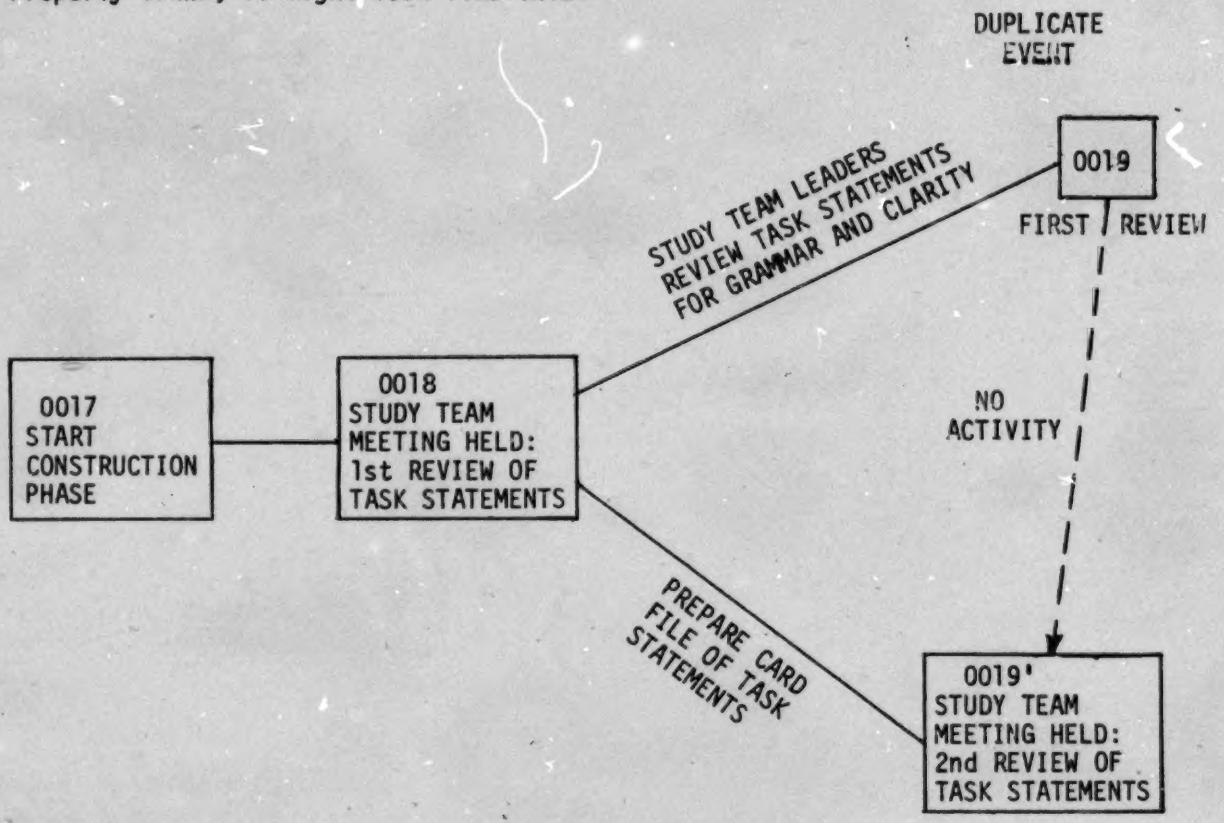
Proper



(Note: Sometimes direction arrows are used on all activity lines, but this is not necessary when the left to right "flow" of the network makes it obvious which is the successor event.)

If two project activities do, in fact, start and end with the same two events and this relationship must be shown, confusion can be avoided by adding a "duplicate event" and a "no-work" or "dummy" activity.

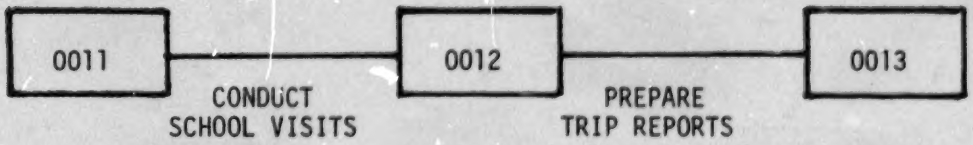
For example, suppose that after the first study team meeting is held (in the Task Inventory Construction Phase), two activities are to be conducted simultaneously -- 1) the study team leaders are to review all task statements for grammar and clarity, and 2) other team members are to transcribe from rough notes all candidate task statements onto 3 x 5 cards for filing. Properly drawn, it might look like this:


DUPLICATE EVENT
0019
FIRST REVIEW
STUDY TEAM LEADERS REVIEW TASK STATEMENTS FOR GRAMMAR AND CLARITY
0017 START CONSTRUCTION PHASE
0018 STUDY TEAM MEETING HELD: 1st REVIEW OF TASK STATEMENTS
NO ACTIVITY
PREPARE CARD FILE OF TASK STATEMENTS
0019' STUDY TEAM MEETING HELD: 2nd REVIEW OF TASK STATEMENTS

Types of networks. There are two general types of PERT networks; they can be used singly or in combination.

1. Event-Oriented Networks: If the predecessor and successor events are well-defined, the activity between them may be obvious. Many PERT networks are drawn using only "event descriptions". For example:

2. Activity-Oriented Networks: This network would describe only the activities and let these define the events implicitly. For example:



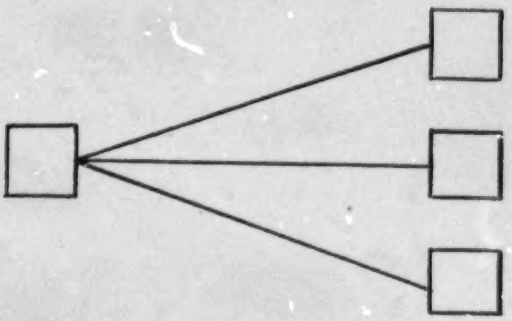
Clarity is sometimes improved by using both precisely defined events and activities. However, if the PERT network is to be displayed (such as on a bulletin board), and easily read, the combination of event and activity oriented networks can clutter the diagram and make it difficult to interpret. This is especially true if time estimates are to be included for display. Our recommendation is that study teams select the one type of network they are most comfortable working with and be consistent in describing it, i.e., not change from event descriptions to activity descriptions. Although the generalized network in Appendix A is an event-oriented network, it could easily be converted to an activity oriented network by a study team

if desired.

PERT SYMBOLS

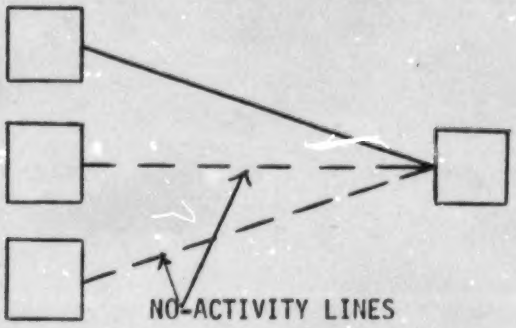
PERT events were originally represented by circles. Later, squares were adopted. Obviously ovals or ellipses are also satisfactory. Other shapes are also used -- hexagons, diamonds, triangles, etc. These are often used for special identification. For example, the hexagon may identify an event associated with the Study Phase, a diamond may identify one associated with the Task Inventory Administration Phase, etc. Such conventions are not fixed by firm rules. When a number of activities emerge from a single event, this group of activities is called a "burst". Such a burst is typically found at the beginning of a project.

Example:



A group of activities that all terminate in a single event is called a "merge". Such a merge is typically found at the end of a project and frequently contains no-activity lines which are required in order to eliminate dangling events.

Example of a "merge":



CHAPTER IV

TIME ESTIMATES

Basically, the PERT approach is a method for (1) describing the logical structure of a project as a network of interdependent activities and events, (2) entering time estimates into this structure or network, and (3) analyzing the schedule implied by the combination of time estimates and the network. This chapter deals with the second of these parts -- the method of introducing time estimates.

To calculate the expected time required for each activity, PERT uses three time estimates: (1) the shortest (optimistic), (2) the longest (pessimistic), and (3) the most likely.

TYPE OF TIME ESTIMATE	SYMBOL	DESCRIPTION
1. The Optimistic (shortest) Estimate	o	The time required when everything goes properly.
2. The Pessimistic (longest) Estimate	p	The time required when everything goes wrong.
3. The most likely Estimate	m	The time required when some things go right, and some go wrong.

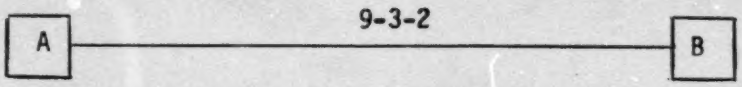
For example, suppose it is known that the same activity (such as: "conduct school visits") has been carried out 11 times during OF studies over the past two years, and the following time spans have occurred:

ACTUAL TIME SPAN FOR ACTIVITY (WEEKS)	FREQUENCY THAT TIME SPANS OCCURRED
2	1
3	4
5	3
6	2
9	1
	11

The optimistic (shortest) span (o) would be 2 weeks, the pessimistic (longest) span (p) would be 9 weeks, and the most likely (m) would be 3 weeks (it occurred more frequently than any other).

These three time estimates are used because PERT is a technique which must depend on them to plan for an uncerain future.

It is recommended that the Study Team in charge of each upcoming OF study be responsible for estimating time requirements for the PERT network. The time estimates should be recorded in the PERT network diagram in the following manner:



The pessimistic, most likely, and optimistic time estimates are placed, in that order, above or adjacent to the activity line.

RULES FOR MAKING TIME ESTIMATES

The purpose of the three PERT time estimates is to reflect uncertainty in a meaningful way. There are several important considerations in making these estimates:

1. The three time estimates must all be based on the same activity performed in the same way.

This means that none of the three estimates should be made on the basis of assuming changes brought about by such things as:

a. method of doing the job
b. number of people working
c. use of overtime
d. work quality

2. The time-span estimates should be made on the assumption that the predecessor event has actually been completed.

This means giving no consideration to any knowledge of complications involved in the completion of the preceeding event. Whatever those complications might be, they must be considered only in time estimates for the activity leading up to that predecessor event.

3. Similarly, the estimates for one activity should not be based on foreseen difficulties associated with succeeding activities.

EXPECTED TIME (t_e)

From the three time estimates [shortest (o), longest (p) and most likely (m)], the "expected" or average time to complete an activity can be calculated. The expected time (t_e) for completing any activity is the time equally likely, or unlikely, to be required. Therefore, t_e represents a time estimate that has a 50-50 chance of being the actual time within which an activity will be completed.

PERT uses the following weighted average to determine t_e, given the time estimates o (optimistic), p (pessimistic), and m (most likely).

$$t_e = \frac{o + 4m + p}{6}$$

Established practice weights the most likely time (m) by four because it occurs most frequently. Using the example on page 24, t_e would be calculated as follows:

$$t_e = \frac{2 + 4(3) + 9}{6} = \frac{23}{6} = 3.83 \text{ weeks}$$

Thus, the expected time to complete the activity (conducting school visits in the example) is estimated to be 3.8 weeks.

GUIDELINES FOR MAKING TIME ESTIMATES

As mentioned earlier, the Study Team is charge of a forthcoming OF study should be responsible for estimating time requirements. In addition to considering the budget available for the OF study, and the competence of personnel to be used in conducting the study, time estimates should be

made on the basis of:

1. The best available information on the "history of experience" with other OF studies.
2. The type of OF to be studied.

Utilizing past experience. A general way to use past experience in making time estimates might be as follows:

1. Each officer of the team independently attaches time estimates (o, m, and p) for each activity in the network.
2. Officers examine PERT network together and revise initial time estimates.
3. The Study Unit submits its network with time estimates to other Study Teams for review and comment and revises time estimates as appropriate.
4. Officers of the Study Team meet with senior staff NCOs who are working with them and review preliminary time estimates. Attempt is made to reach consensus on each time estimate.
5. Study Team revises time estimates and calculates expected time (t_e) for each activity.
6. Study Team submits network with time estimates to Head, Task Analysis Section for information and approval.

In practice, there may be several variations in the procedure to estimate time requirements. In general, however, the approach should entail utilizing past experience whenever practicable.

Adapting time estimates to the OF to be studied. Unique features of each OF to be studied are likely to necessitate adjustments of time estimates made on the basis of past experience alone. In fact, if the OF is substantially different and past experience is, therefore, of limited value, it may be wise to wait until after the Study Phase to estimate time requirements. Sponsor and monitor information may provide a superior substitute for past experience in estimating time requirements.

In most cases, time estimates for the same activities in different OF studies will vary somewhat. For example, the geographical locations of schools, commands, and other places requiring on-site visits will result in varying travel time estimates. An OF with a larger Marine population may require more time in certain activities such as inventory administration. Whether the OF is a high- or low-technology field may also influence time estimates. For example, a high-technology OF may require substantially more time in task inventory construction than a low-technology OF. However, a low-technology OF may require more time in inventory administration.

Indeed, estimations of time requirements might be more accurately determined after the Study Phase if the impact of differences between previous OF studies and the subject OF study cannot be assessed beforehand.

SUMMARY

Determining expected time required for any activity involves three time estimates: "optimistic time", an estimate of time required if everything goes exceptionally well; "pessimistic time", an estimate based on the assumption that any logically conceivable bad luck -- other than major disaster -- will be encountered; and "most likely time", an estimate of what the Study Unit reasonably expects will be necessary to do the job.

Some time estimates, such as for routine activities connected with any OF study, will perhaps be more accurate. Others, especially for activities occurring toward the end of the OF study, will be more difficult to determine, and will perhaps be less accurate. However, time estimates for all activities are essential to plan for effective and efficient use of resources. In practice, as the OF study progresses, actual time required will be substituted for expected time, and the resultant effects on remaining project activities and time available can be easily determined.

CHAPTER V

COMPLETING THE TOTAL PERT SCHEDULE

In the previous chapter, a method was described for determining expected time (t_e) for each activity in the PERT network. Completion of the PERT schedule involves summing the t_e's along every possible path from start to finish of the project.

The path which yields the largest t_e sum, and thus represents the longest path from start to finish of the project, is called the critical path. It is so called because it is the only path that includes all events and therefore time savings or losses on this path directly hasten or delay the project completion date. All other paths are sub-critical, but may become critical if delays are encountered along them.

Figure 1 on the next page illustrates a hypothetical PERT network. The events, represented by numbered circles, are connected by activity lines on which there are shown number series. As explained in Chapter IV, these numbers represent the pessimistic, most likely, and optimistic estimates of the activity time required between events. For example, the activity line connecting Event 1 to Event 2 carries the numbers 30-12-6, which represent the pessimistic, most likely, and optimistic time estimates, respectively. The figure in parentheses (14.0) under this same activity line is the ex-

Figure 1

Hypothetical Network

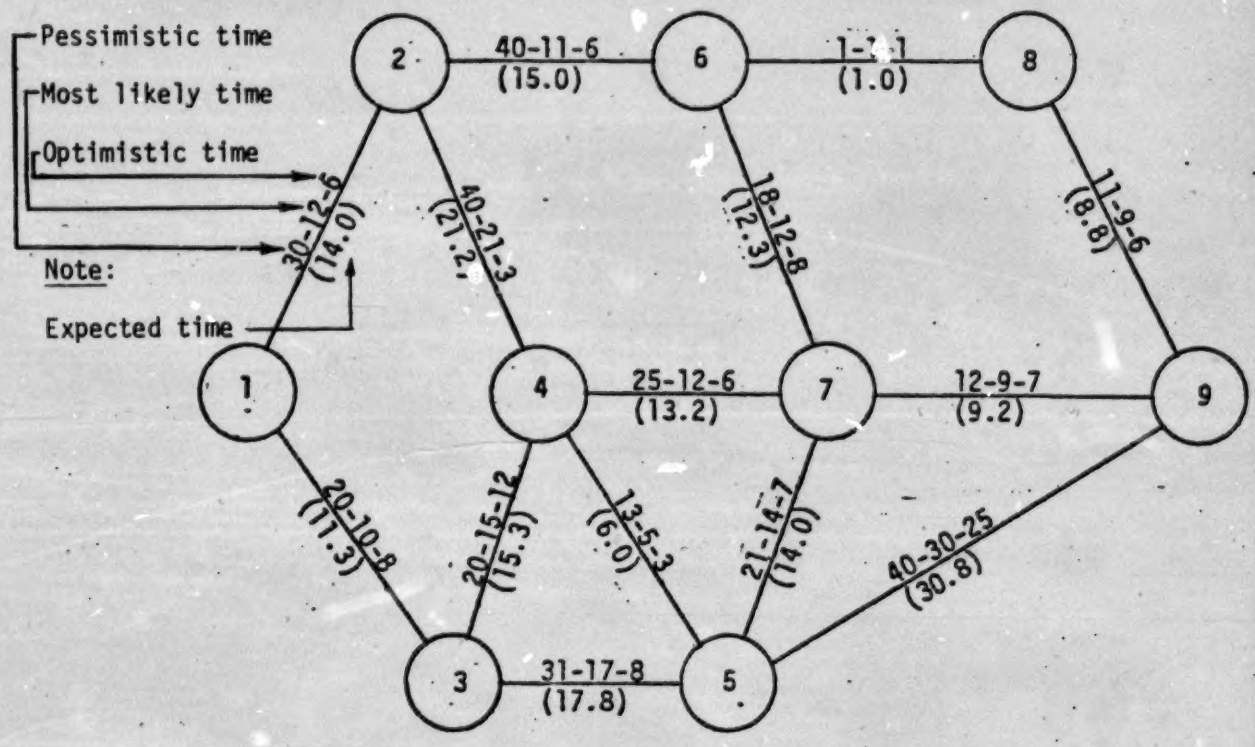


Table 1

ACTIVITIES		t_e
Beginning Event	End Event	Expected Activity Time
1	2	14.0
1	3	11.3
2	4	21.2
3	4	15.3
3	5	17.8
4	5	6.0
2	6	15.0
4	7	13.2
5	7	14.0
6	7	12.3
6	8	1.0
5	9	30.8
7	9	9.2
8	9	8.8

pected time, t_e. Table 1 lists all the activities and their t_e's for the network.

The steps for determining the critical path and completing the PERT schedule for the network in Figure 1 are as follows:

Step 1

The first step is to accumulate the expected times, t_e's, to obtain the Accumulated Expected Time, T_E. T_E for any event is the longest time to that event. For example, in Figure 1, there are six paths from Event 1 to Event 7 with t_e's summed as follows:

Path 1 to 2 to 6 to 7	$\Sigma t_e = 14.0 + 15.0 + 12.3 = 41.3$
Path 1 to 2 to 4 to 7	$\Sigma t_e = 14.0 + 21.2 + 13.2 = 48.4$
Path 1 to 2 to 4 to 5 to 7	$\Sigma t_e = 14.0 + 21.2 + 6.0 + 14.0 = 55.2$
Path 1 to 3 to 5 to 7	$\Sigma t_e = 11.3 + 17.8 + 14.0 = 43.1$
Path 1 to 3 to 4 to 7	$\Sigma t_e = 11.3 + 15.3 + 13.2 = 39.8$
Path 1 to 3 to 4 to 5 to 7	$\Sigma t_e = 11.3 + 15.3 + 6.0 + 14.0 = 46.6$

The maximum critical path of $\Sigma t_e = T_E = 55.2$ for the expected time to Event 7. Similarly, the T_E's of the other events are computed and summarized in Table 2 (see also Figure 2).

Table 2

ACTIVITIES		t_e	T_E
Beginning Event	End Event	Expected Activity Time	Accumulated Expected Time
1	2	14.0	14.0
1	3	11.3	11.3
2	4	21.2	35.2
3	4	15.3	26.6
3	5	17.8	29.1
4	5	6.0	41.2
2	6	15.0	29.0
4	7	13.2	48.4
5	7	14.0	55.2
6	7	12.3	41.3
6	8	1.0	30.0
5	9	30.8	72.0
7	9	9.2	64.4
8	9	8.8	38.8

Step 2

The second step is to determine the latest time, T_L, at which each event can be completed and still accomplish the total project on time. If a scheduled end date has not been established, then for the end event: $T_L = T_E$.

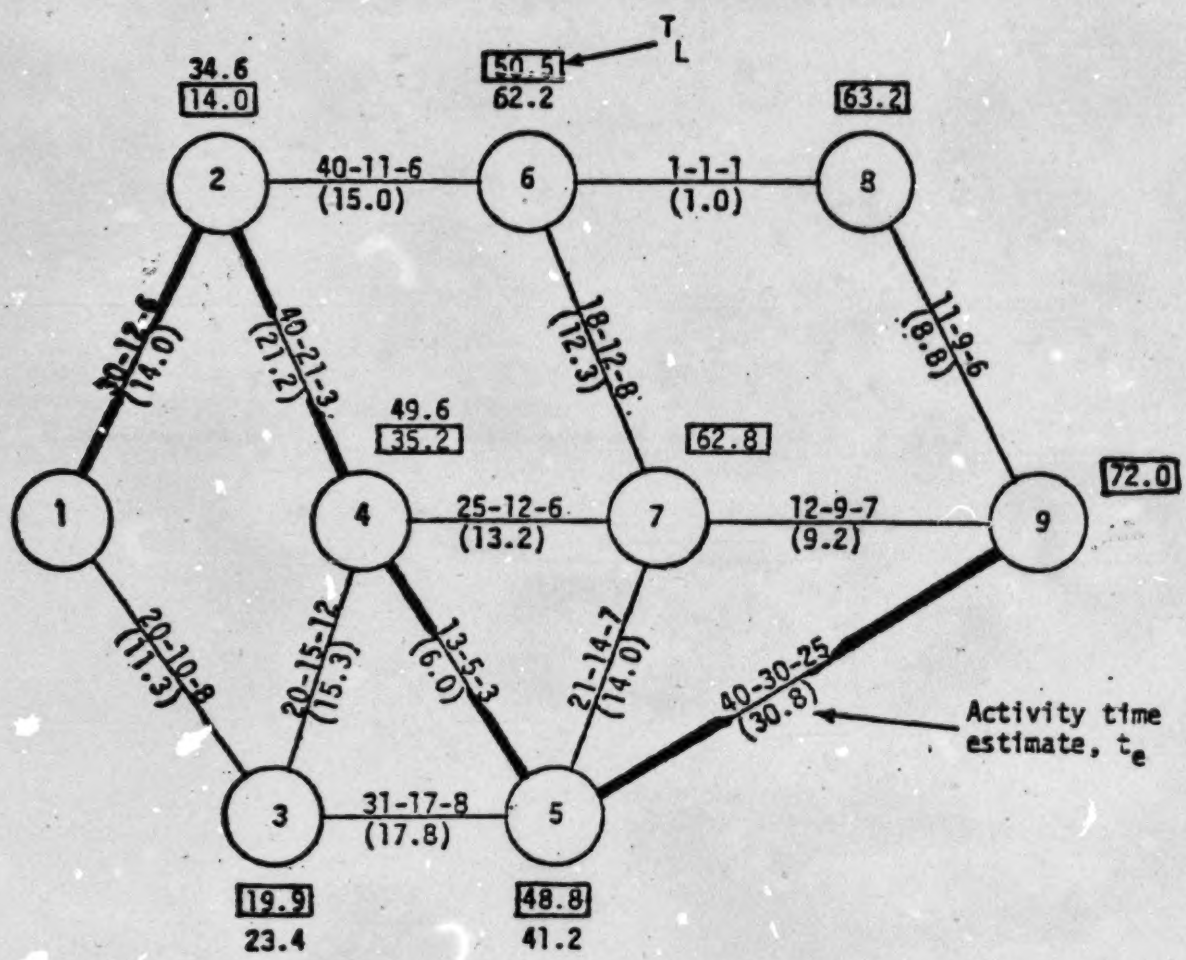
In Figure 2 on the following page, the longest (critical) path to achieve Event 9 is the Accumulated Expected Time, $T_E = 72.0$. In order to find T_L for Event 8, subtract t_e for activity 8 - 9 to obtain:

$$T_L = 72.0 - 8.8 = 63.2$$

For Event 7:

$$T_L = 72.0 - 9.2 = 62.8$$

Figure 2



Note: Heavier lines indicate longest (critical) path to accomplish Event 9

Event 6 is the beginning of two activities, 6 - 7 and 6 - 8. Two possible values of T_L would be obtained by subtraction:

$$T_L = 62.8 - 12.3 = 50.5$$

$$T_L = 63.2 - 1.0 = 62.2$$

When more than one value of T_L may be computed, the smallest one is used.

In this case, both values are written above Event 6 in Figure 2. The smaller one is indicated by the box around it. From Figure 2, it is easy to continue computing the T_L's.

Step 3

The final step is to find the slack time or float for each activity. Slack is the difference between time required for an activity and time available as planned.

Since accumulated time (T_E) represents the longest time to an event, or time required, and latest time (T_L) represents the amount of time available to complete the total project on time, the difference indicates slack time. Therefore, $T_E - T_L$ = Slack Time. These figures are shown in Table 3, the Completed PERT Schedule, below:

Table 3

Completed PERT Schedule

ACTIVITIES		t_e	T_E	T_L	SLACK
Beginning Event	End Event	Expected Activity Time	Accumulated Time	Latest Time for End Event	$(T_L - T_E)$
1	2	14.0	14.0	14.0	0.0
1	3	11.3	11.3	19.9	8.6
2	4	21.2	35.2	35.2	0.0
3	4	15.3	26.6	35.2	8.6
3	5	17.8	29.1	41.2	12.1
4	5	6.0	41.2	41.2	0.0
2	6	15.0	29.0	50.5	21.5
4	7	13.2	48.4	62.8	14.4
5	7	14.0	55.2	62.8	7.6
6	7	12.3	41.3	62.8	21.5
6	8	1.0	30.0	63.2	33.2
5	9	30.8	72.0	72.0	0.0
7	9	9.2	64.4	72.0	7.6
8	9	8.8	38.8	72.0	33.2

It should be noted that slack time in this example could be positive (more time available than is required), or zero (equal time available and required). In actuality, also, there may be negative slack (less time available than required). PERT analysis determines the slack in each activity in a network, and thereby indicates where trouble is likely (negative slack), potential trouble exists (zero slack), or no trouble exists (positive slack).

CHAPTER VI

SUMMARY: MANAGING OCCUPATIONAL FIELD STUDIES WITH PERT

Pert is a tested planning device for research-oriented operations such as conducting an OF study. In general, a PERT system could be used by OMU in two major ways. First, each Study Team could develop the PERT schedule for a new OF study, and utilize the schedule as a control and monitoring device for its own work. PERT should allow a team to anticipate problems or "rough spots" in an OF study and plan for them. Its use should also improve coordination and resource utilization.

Second, the use of PERT would facilitate and enhance coordination between each Study Unit and sub-units within the Operations Support Unit. At the top management level of OMU, PERT could serve as a basis for budget preparation, improved resource allocation, and be utilized as a performance and a progress assessment tool.

STRENGTHS AND WEAKNESSES OF PERT

There are five strong advantages of PERT. First, it imposes a planning discipline, because it is impossible to make a time-event analysis without planning and seeing how the pieces fit together. Second, it forces planning all down the line, because each subordinate must plan the event for which he is responsible. Third, it concentrates attention on critical

elements that may need correction. Fourth, it makes possible a kind of forward-looking control; a delay will affect succeeding events, and possibly the critical path, unless somehow the time can be made up by shortening some future action. Fifth, the network system makes possible aiming of reports and pressure for action at the right spot and level in the organization structure at the right time.

PERT is not a cure-all. It will not do the planning, although it forces planning. It will not make control automatic, although it establishes an environment where sound control principles may be appreciated and used. It supplements rather than substitutes for sound management decisions and action.

SUMMARY

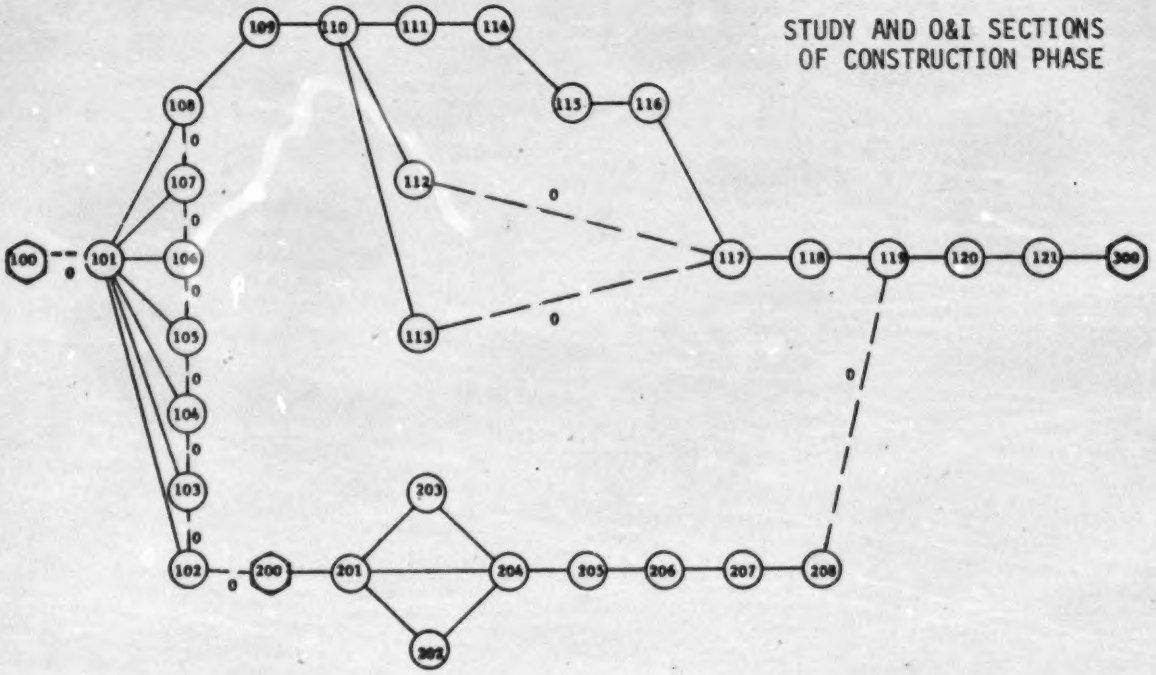
In summary, the PERT system involves:

- Identification of a sequence of specific events which must occur before the project can be completed.
- Sequencing of the events and establishing interdependencies among these events in the development of a project network.
- Estimating the time required and the activities necessary to schedule and achieve each and all of these events.
- Designing an analysis and evaluation procedure based upon these data.
- Establishing information channels to notify all personnel concerned of achievements, defaults, and changes.

APPENDIX A

GENERALIZED PERT NETWORK
FOR
OMU PROJECTS

STUDY AND O&I SECTIONS OF CONSTRUCTION PHASE

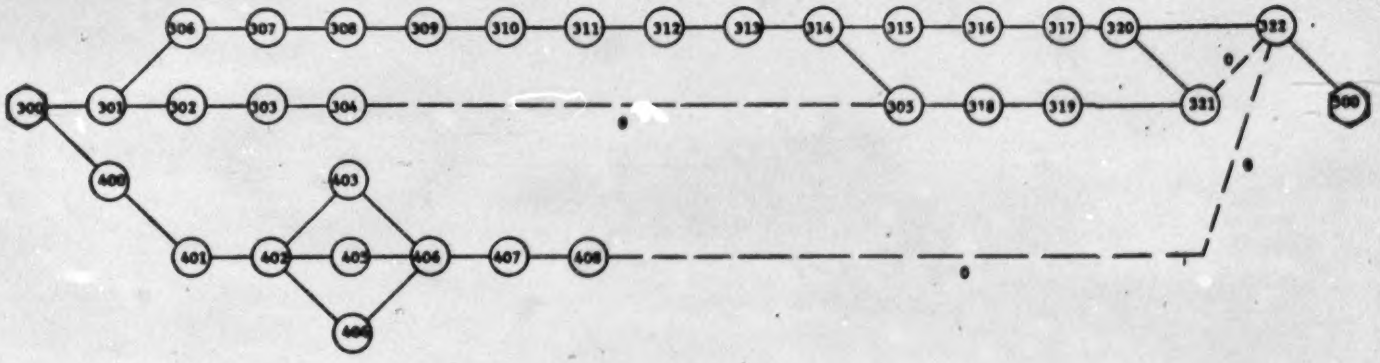


ACTIVITY NO.	DESCRIPTION	EVENT NO.	DESCRIPTION
		100-	* S Study
100-101	Zero-time activity		
		101-	S Study Section of Construction Phase
101-102	Obtain MMS printouts (GIMMIS extracts)	102-	MMS printouts obtained
101-103	Prepare GAR extraction	103-	GAR extraction C**
101-104	Obtain historical data from Occupational Analysis	104-	Historical data obtained
101-105	Prepare EPAD extraction	105-	EPAD extraction C
101-106	Prepare MOS extraction	106-	MOS extraction C
101-107	Obtain MCI course packages	107-	Course packages obtained
101-108	Sponsor/Monitor meet preparation	108-	Meeting preparation C
102-103	Zero-time activity		
102-200	Zero-time activity		
103-104	Zero-time activity		
104-105	Zero-time activity		
105-106	Zero-time activity		
106-107	Zero-time activity		
107-108	Zero-time activity		
108-109	Team "in-house" preparation	109-	Team preparation
109-110	Conduct Monitor/Sponsor meeting	110-	Monitor/Sponsor meeting held
110-111	Establish liaison with schools	111-	Liaison established
110-112	Obtain other studies	112-	Other studies obtained
110-113	Make Sponsor/Monitor recommended contacts	113-	Contacts made
111-114	Prepare official letters and mail	114-	Letters sent
112-117	Zero-time activity		
113-117	Zero-time activity		
114-115	Obtain security and/or area clearances	115-	Clearances obtained
115-116	Prepare orders	116-	Orders C
116-117	Make all travel arrangements	117-	Travel arrangements C
117-118	Conduct school visits	118-	School visits
118-119	Prepare trip report	119-	Trip report C
119-120	Prepare phase report	120-	Phase report C
120-121	Conduct team meeting to review Study Section of Construction Phase	121-	Team meeting held
121-300	Zero-time activity	200-	Optional event: O & I Section of Construction Phase S
200-201	Determine locations for O & I cost of O & I, and number of Marines to be O & Ied	201-	Locations, members and costs determined
201-204	Obtain security and/or area clearances	204-	Travel arrangement C
201-202	Prepare orders and itineraries for trips.	202-	Orders and itineraries C
201-203	Establish liaison	203-	Liaison established
202-204	Make all travel arrangements	204-	Travel arrangements C
203-204	Prepare and send official letters	204-	Travel arrangements C
204-205	Conduct team meeting	205-	Team meeting held
205-206	Travel to O & I locations and hold interviews	206-	Interviews C
207-208	Write trip report	208-	Report C
208-119	Zero-time activity		

*"S" = Started

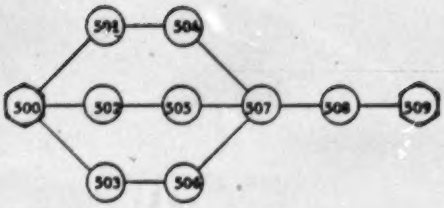
** "C" = Completed

TASK INVENTORY PREPARATION AND PRE-ADMINISTRATION SECTIONS OF CONSTRUCTION PHASE



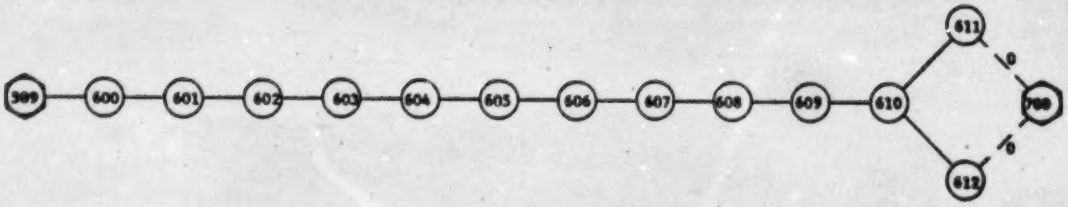
ACTIVITY NO.	DESCRIPTION	EVENT NO.	DESCRIPTION
		300-	Start Task Inventory Section of Construction Phase
300-301	Conduct team meeting to determine valid tasks	301-	Meeting held
301-302	Construct card file of tasks	302-	Card file C
302-303	Conduct team meeting to determine duty areas	303-	Team meeting held
303-304	Assign tasks to duty areas	304-	Assignments C
304-305	Zero-time activity		
301-306	Review task statements for proper grammar and construction	306-	Review C
306-307	Team meeting to determine Part II questions	307-	Team meeting held
307-308	Review Part II for format adherence	308-	Part II review C
308-309	Type draft of inventory	309-	Typing C
309-310	Proofread draft	310-	Proofing C
310-311	Correct draft	311-	Corrections C
311-312	Reproduce proposed task inventory	312-	Reproduction C
312-313	Route proposed task inventory to external agencies for comment	313-	Routing C
313-314	Team meeting to review comments and finalize task inventory	314-	Team meeting held
314-305	Update card file with new tasks	305-	File update C
314-315	Type revised task inventory	315-	Typing C
315-316	Proof typed task inventory	316-	Proofing C
316-317	Correct typed task inventory	317-	Corrections C
305-318	Assign new tasks to duty areas	318-	Assignments C
318-319	Assign variable decode titles	319-	Coding C
319-321	Update files	321-	Update C
317-320	Print task inventory	320-	Printing C
320-321	Update files	321-	Update C
320-322	Proof final task inventory	322-	Proofing C
321-322	Zero-time activity		
322-500	Travel to locations	500-	S Administration phase
300-400	Start pre-administration phase; determine administration locations	400-	Locations determined
400-401	Determine numbers, by rank and MOS, to be administered to at each location and cost of administration phase	401-	Numbers and cost determined
401-402	Establish liaison	402-	Liaison established
402-403	Obtain security clearances	403-	Clearances obtained
402-404	Prepare response book mailing	404-	Mailing C
402-405	Prepare and send official letters	405-	Letters sent
403-406	Plan trip itineraries	406-	Travel arrangements C
404-406	Prepare orders	406-	Travel arrangements C
405-406	Prepare travel requests	406-	Travel arrangements C
406-407	Prepare and submit trip itinerary to ONU	407-	Itinerary received by ONU
407-408	Pick up tickets	408-	Tickets picked up
408-322	Zero-time activity		

ADMINISTRATION PHASE



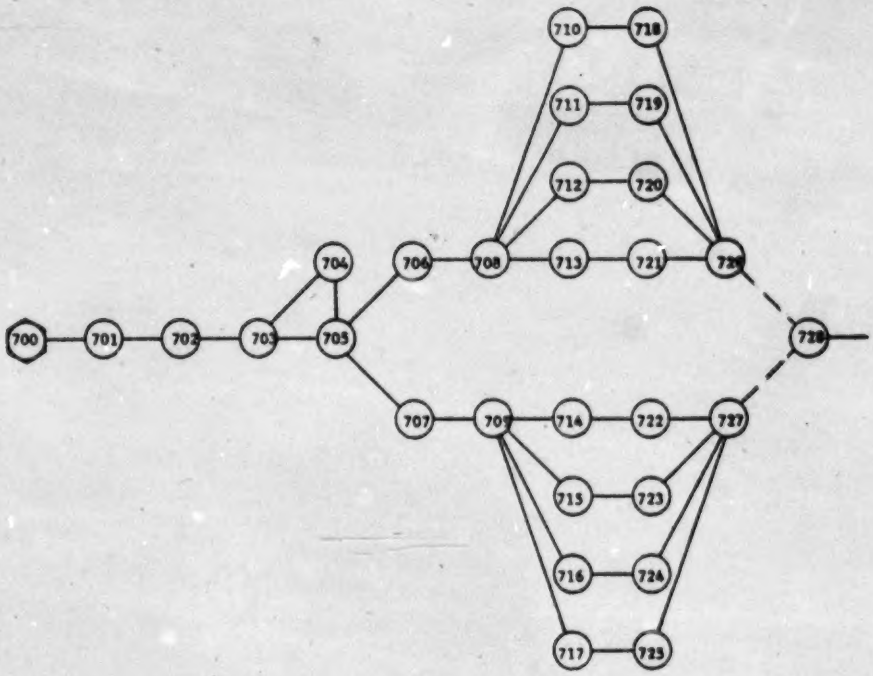
ACTIVITY NO.	DESCRIPTION	EVENT NO.	DESCRIPTION
500-501	Conduct overseas administration	501-	Overseas administration C
500-502	Conduct West Coast administration	502-	West Coast administration C
500-503	Conduct East Coast administration	503-	East Coast administration C
501-504	Pack and mail overseas response books to OMU	504-	Mailing C
502-505	Pack and mail West Coast response books to OMU	505-	Mailing C
503-506	Pack and mail East Coast response books to OMU	506-	Mailing C
504-507	Write overseas trip report	507-	Trip report C
505-507	Write West Coast trip report	507	Trip report C
506-507	Write East Coast trip report	507-	Trip report C
507-508	Write phase report and update files	508-	Report and file update C
508-509	Conduct Phase II review	509-	Review C

PROCESSING PHASE

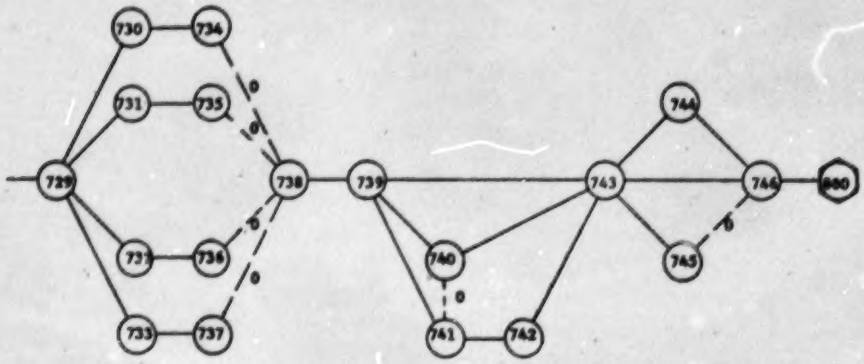


ACTIVITY NO.	DESCRIPTION	EVENT NO.	DESCRIPTION
		509-	S Processing Phase
509-600	Conduct accounting for all books	600-	Accounting C
600-601	Clean books	601-	Cleaning C
601-602	Insert header pages	602-	Inserting C
602-603	Deliver books to DPI for processing	603-	Processing C
603-604	Send processed books and edit sheets (print-outs) to OMU	604-	Books and sheets received
604-605	Check edit for rejected books and books with errors	605-	Checking C
605-606	Correct books	606-	Corrections C
606-607	Reprocess corrected books	607-	Reprocessing C
607-608	Team removes duplicate cases from Master Data File	608-	Duplicate case removal C
608-609	Run input standard	609-	Input standard run C
609-610	Audit input standard	610-	Audit C
610-611	Request hierarchical diagram	611-	Diagram received
610-612	File booklets at OMU	612-	Filing C
611-700	Zero-time activity		
612-700	Zero-time activity		
		700-	Processing Phase C

ANALYSIS PHASE

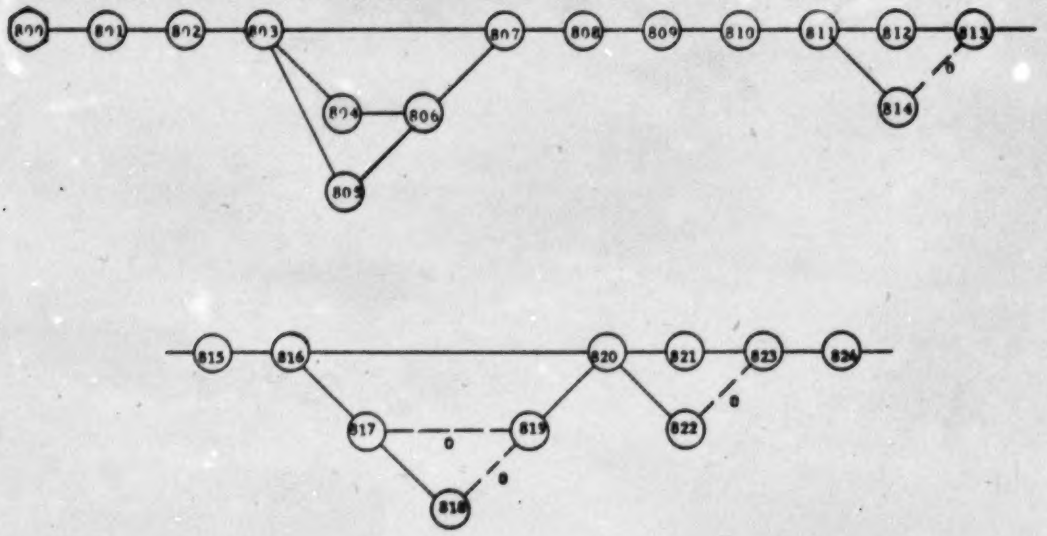


ACTIVITY NO.	DESCRIPTION	EVENT NO.	DESCRIPTION
700-701	Review hierarchical diagram	700-	S Analysis Phase
701-702	Prepare "pre-analysis" meeting folders	701-	Review C
702-703	Conduct "pre-analysis" meeting	703-	Meeting held
703-704	Request GRPMBR (if desired)	704-	GRPMBR obtained
703-705	Divide initial groups for initial analysis	705-	Group division C
705-706	Request Group I JOBDECs	706-	Group I JOBDECs received
705-707	Request Group II JOBDECs	707-	Group II JOBDECs received
706-708	Group I review initial JOBDEC and compare with MOS	708-	Initial review C
707-709	Group II review initial JOBDEC and compare with MOS	709-	Initial review C
708-710	Group I request special JOBDECs	710-	JOBDECs received
708-711	Group I request GRPDIFs	711-	GRPDIFs received
708-712	Group I request PRTVAR	712-	PRTVAR received
708-713	Group I request other CODAP programs as required	713-	Other programs received
709-714	Group II request special JOBDECs	714-	JOBDECs received
709-715	Group II request GRPDIFs	715-	GRPDIFs received
709-716	Group II request PRTVAR	716-	PRTVAR received
709-717	Group II request other CODAP programs as required	717-	Other programs received
710-718	Group I analysis of JOBDEC	718-	Analysis C
711-719	Group I analysis of GRPDIF	719-	Analysis C
712-720	Group I analysis of PRTVAR	720-	Analysis C
713-721	Group I analysis of other CODAP programs	721-	Analysis C
714-722	Group II analysis of special JOBDECs	722-	Analysis C
715-723	Group II analysis of GRPDIF	723-	Analysis C
716-724	Group II analysis of PRTVAR	724-	Analysis C
717-725	Group II analysis of CODAP	725-	Analysis C
718-726	Validate JOBDEC analysis	726-	Validations C
719-726	Validate GRPDIF analysis	726-	Validations C
720-726	Validate PRTVAR analysis	726-	Validations C
721-726	Validate other CODAP analysis	726-	Validations C
722-727	Validate JOBDEC analysis	727-	Validations C
723-727	Validate GRPDIF analysis	727-	Validations C
724-727	Validate PRTVAR analysis	727-	Validations C
725-727	Validate other CODAP analysis	727-	Validations C
726-728	Zero-time activity		
727-728	Zero-time activity	728-	S team meeting

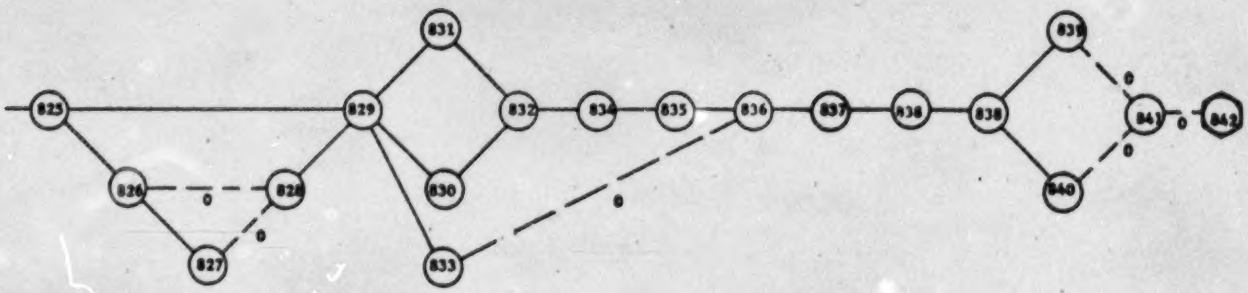


ACTIVITY NO.	DESCRIPTION	EVENT NO.	DESCRIPTION
728-729	Conduct team meeting, compare Group I and II analysis	729-	Meeting C
729-730	Request new JOBDECs as required	730-	JOBDECs received
729-731	Request new GRPDIFs as required	731-	GRPDIFs received
729-732	Request special JOBDECs as as required	732-	JOBDECs received
729-733	Request other CODAP as required	733-	CODAP received
730-734	Analyze JOBDECs	734-	Analysis C
731-735	Analyze GRPDIFs	735-	Analysis C
732-736	Analyze special JOBDECs	736-	Analysis C
733-737	Analyze other CODAP	737-	Analysis C
734-738	Zero-time activity		
735-738	Zero-time activity		
736-738	Zero-time activity		
737-738	Zero-time activity		
		738-	S team meeting
738-739	Conduct team meeting to determine valid jobs in OF	739-	Meeting C; valid jobs determined
739-740	Obtain JOBDECs for valid jobs	740-	JOBDECs received
739-743	Compare valid jobs with current structure	743-	Determination of structure, training, classification, and assignment problems C
739-741	Obtain Part II VARSUM	741-	VARSUM received
740-743	Compare JOBDECs with POIs and MOS manual	743-	Determination of structure, training, classification, and assignment problems C
740-741	Zero-time activity		
741-742	Obtain special VARSUM for JOBDECs	742-	Special VARSUM received
742-743	Analyze VARSUMs; compare with other data on class classification and assignment	743-	Determination of structure, training, classification, and assignment problems C
743-744	Obtain additional information as required	744-	Information received
743-745	Review analysis data	745-	Analysis C
743-746	Review cost data	746-	Recommended solutions C
744-746	Additional information analyzed	746-	Recommended solutions C
745-746	Zero-time activity		
746-800	Update files	800-	S Report phase

REPORT AND STAFFING PHASE



ACTIVITY NO.	DESCRIPTION	EVENT NO.	DESCRIPTION
800-801	Team data consolidated into outline report by assistant team leader	801-	Outline report C
801-802	Review and decision on content by team leader	802-	Content decision phase C
802-803	Draft rough report	803-	Rough draft C
803-807	Monitor/Sponsor briefed	807-	Report C
803-804	Type rough copy and proofread	804-	Typed rough C
803-805	Assemble appendices	805-	Appendices C
804-806	Type smooth copy and proof-read	806-	Typed smooth C, appendices C
805-806	Photo reproduce appendices	806-	Typed smooth C, appendices C
806-807	Assemble report	807-	Report C
807-808	Submit to Director, OMU for comments and review	808-	OMU Director's review C
808-809	Rewrite as required	809-	Rewrite C
809-810	Submit report to Director, MP, and brief	810-	MP Director's review C
810-811	Rewrite as required	811-	Rewrite C
811-812	Type and proofread	812-	Smooth copy C
811-814	Prepare initial routing sheet	814-	Routing sheet C
814-813	Zero-time activity		
812-813	Assemble and reproduce report	813-	Report C
813-815	Conduct initial routing	815-	Routing C
815-816	Review comments from initial routing	816-	Review C
816-820	Update files	820-	File update and rewrite C
816-817	Resolve non-concurrences	817-	Non-concurrence resolved
817-818	Submit unresolved differences to Director, OMU	818-	Resolution of differences C
817-819	Zero-time activity		
818-819	Zero-time activity	819-	S rewrite
819-820	Rewrite as required	820-	File update and rewrite C
820-821	Type and proofread	821-	Smooth copy C
820-822	Prepare Manpower Department route sheet	822-	Manpower Department route sheet C
821-823	Reproduce and assemble report for second routing	823-	Report C
822-823	Zero-time activity		
823-824	Conduct second routing	824-	Second routing C



ACTIVITY NO.	DESCRIPTION
824-825	Review comments from second routing
825-829	Update files
825-826	Resolve differences
825-827	Submit unresolved differences to Director, OMU
825-828	Zero-time activity
827-828	Zero-time activity
828-829	Rewrite as required
829-830	Type and proofread
829-831	Prepare brief for Director, MP division
820-832	Submit report for MP Director's review
831-832	Brief MP Director
829-833	Prepare final route sheet
832-834	Rewrite as required
833-836	Zero-time activity
834-835	Type and proof
835-836	Reproduce and assemble
836-837	Routing to Chief of Staff
837-838	Action by Chief of Staff
838-839	Update files
838-840	Check files for duplicate tape
839-841	Zero-time activity
840-841	Zero-time activity
841-842	Zero-time activity

EVENT NO.	DESCRIPTION
825-	Review C
829-	File update and rewrite C
826-	Differences resolved
827-	Resolution of differences C
828-	Start rewrite
829-	File update and rewrite C
830-	Smooth copy C
831-	Brief preparation C
832-	MP Director's briefing and review C
832-	MP Director's briefing and review C
833-	Route sheet C
834-	Rewrite C
835-	Smooth Copy C
836-	S final routing to Chief of Staff
837-	Routing C
838-	Chief of Staff routing C
839-	File update C
840-	File check C
841-	Study C
841-	Study C
842-	End of study

APPENDIX B

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SELECTED ANNOTATED

BIBLIOGRAPHY

Archibald, Russell D., and Richard L. Villoria. Network Based Management Systems (PERT/CPM), New York: John Wiley & Sons, Inc., 1967.

The authors present a very in-depth and extensive examination of PERT. In addition to an examination of basic PERT concepts, there is an entire section of case studies. Included in the appendices is an analytical study of the PERT assumptions and a very extensive glossary.

Baker, Bruce N., and Rene' L. Eris. An Introduction to PERT-CPM, Richard D. Irwin, Inc., 1964.

This is a very concise and to-the-point explanation of PERT and CPM (Critical Path Method.) Of particular interest are the discussion and illustrations of different networking logic techniques. The authors' emphasize networks which are activity-oriented with event identification. The chapter on data processing includes sample data transmittal sheets and computer print-outs. Chapter 6, Structuring of PERT Data, presents valuable examples of a project work breakdown structure for large, complex projects.

Evarts, Harry F. Introduction to PERT, Boston: Allyn and Bacon, Inc., 1964.

PERT is presented as an event-oriented technique rather than activity or activity-event oriented. Chapter 2, The PERT Network, is

very comprehensive, covering networking concepts, time estimates, dummy activities, and lead times. Time calculations are given extensive coverage, and the author has also included review questions for each chapter and glossary of PERT terms.

Levin, Richard I., and Charles A. Kirkpatrick. Planning and Control with PERT/CPM, New York: McGraw Hill, Inc, 1966.

Levin and Kirkpatrick present an extremely well rounded and understandable discussion of PERT. Chapters 2, "PERT Fundamentals," 3, "Work Breakdown Schedule," and 5, "Networking Principles," clearly illustrate the fundamental concepts, practical applications, and development of activity-event oriented PERT. Time and probability, two of the most important aspects of PERT, are discussed in a straightforward manner which avoids complex statistical theory. Separate chapters covering the computer in PERT applications and the Critical Path Method (CPM) are also included.

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A. BOOKS

Archibald, Russell D., and Richard L. Villoria. Network Based Management Systems (PERT/CPM), New York: John Wiley & Sons, Inc.,

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Miller, R. W. "How to Plan and Control with PERT." Harvard Business Review, March-April, 1972, pp. 101 ff.

Mueller, M. W., and W. A. Nielsen, PERT Training Manual, Lockheed California Company, January, 1962.